CONSERVING BOTANICAL DIVERSITY ON A GLOBAL SCALE[1]

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ABSTRACT

As the world moves toward the twenty-first century, it seems ill prepared to cope with increasing social, economic, and demographic problems. It is not surprising that loss of biodiversity is not perceived as a problem by many people. Current depletion rates are reaching serious proportions. Attention is particularly focused on losses to moist tropical forests and the need to monitor this at a variety of levels: area and quality of habitat, species extinction, and loss of genetic variability. However, conservation of tropical forest must not be at the expense of other habitats and ecosystems. Alarming losses are occurring in many other systems, such as wetlands and Mediterranean shrublands. The plants of even such recently pristine regions as the Antarctic are under pressure from human influences. Future scenarios are not easy to construct as there are many uncertainties. Major deleterious factors could be: global climatic changes, especially through the greenhouse effect and alteration in the ozone layer around the earth; soil depletion, genetic loss, and climatic changes resulting from tropical forest loss; increase in the human population; economic instability and imbalances in distribution of wealth; and decreased resources for research and biological conservation. In view of this, there is need to question whether conventional strategies chiefly involving protected natural areas, botanic gardens, and gene banks can cope with future needs. Focal points for short-term and long-term action are suggested. There is need to understand with greater precision the processes of extinction and to elaborate and test extinction models. Management of modified landscapes is likely to achieve greater prominence in the future but needs to be based on sound biological theory. Conservation managers and biologists will need to be innovative and bold, perhaps making decisions that may be unpopular with some supporters of conservation but may be necessary for the long-term well-being of the biosphere. An increased level of cooperation is necessary; currently this is hampered in some countries by a "free market" philosophy of competitive funding. Adequate resources for conservation are essential, and this means establishing a better case for research and management funding, clearer definition of objectives, and greater accountability by scientists. Perhaps, above all, a new ethic is long overdue, marked by a return to the concept of global and regional commons with recognition of interdependence rather than independence. There is danger in the view that "everyone is a conservationist at heart" unless there is clear understanding of what this means in practical terms to each individual. Perhaps the greatest danger facing conservation is loss of biodiversity by slow attrition. Awareness of the value and wonder of diversity is probably the best safeguard against this, which means that conservation research and management must not only be directed for the good of plants and animals, but must be communicated to people living alongside them.

> If we sell you our land, love it as we've loved it. Care for it as we've cared for it. Hold in your mind the memory of the land as it is when you take it . . . and with all your strength, with all your mind, with all your heart, preserve it for your children—Chief Seattle, 1854.

Recently, I telephoned the head of science at a local high school. During the conversation I asked why there is so little conservation in the senior science syllabus. He thought and answered, "Well, conservation of plants and animals was an issue in the 1970s, but it isn't really an issue now!" One of the questions that we need to address is exactly this: Is biological conservation an important issue today? If the answer is negative, then we are probably wasting our time being here today! Norman Myers (1979, p. 3) succinctly expressed the view of many people:

> Ask a man in the street what he thinks of the problem of disappearing species, and he may well reply that it would be a pity if the tiger or the blue whale disappeared. But he may well add that it would be no big deal, not as compared with crises of energy, population, food and pollution—the 'real' problems. In other words, he cares about disappearing species, but he cares about many other issues more: he simply

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does not see it as a critical issue. If the tiger were to go extinct tonight, the sun would still come up tomorrow morning.

Myers pointed out that his man in the street is quite correct in one respect—by tomorrow morning there is likely to be at least one fewer species on planet Earth than there was this morning.

Diversity is often expressed as numbers of taxa, and commonly we speak of conserving "species." But diversity can be expressed in many other ways such as morphology, size, color, function, range of habitats, and use by people. It is useful to distinguish three principal levels of diversity. Ecological diversity is expressed as diversity of habitats and ecosystems, the diversity we see in a mosaic of forest, grassland, wetland, and other habitat types throughout a landscape. Species diversity is expressed as numbers of taxa, reaching maximum levels in regions with high numbers of locally endemic species. Genetic diversity occurs at the level of genes, the building blocks of life which make one individual and population different from another.

Whatever the measure of diversity, there is little doubt that the world of plants is immensely varied. There are about 235,000 flowering and 270,000 nonflowering extant plant species (Raven et al., 1986; H. Synge, pers. comm., 1988; D. L. Hawkesworth, pers. comm., 1988). They occur in many different habitats from the tropics to polar regions, and from 100 m under the sea to over 6,000 m altitude. An exciting outcome of polar botany in recent years has been the discovery of plants in the Antarctic growing under environmental extremes formerly considered uninhabitable. This includes mosses growing on fumerolic soils of active volcanoes (Broady et al., 1987) and endolithic algae of the dry valleys of southern Victoria Land (Friedmann, 1982). The latter plants live in the interstices just below the surface of coarse-grained rock, demonstrating the persistence of life under the most adverse of environments. Plant diversity is essential to the Earth's biosphere as we know it. With the exception of some sulphur bacteria, all animals are ultimately dependent on the Earth's green mantle of photosynthetic plants.

What Are the Losses?

All species have a limited life in geological terms, whether it be measured in hundreds of thousands or tens of millions of years. But this is poor justification for the frequently offered counter to conservation that: "Because extinctions have always been occurring there is surely nothing to be concerned about. Does it matter if a few more species disappear?" This argument ignores the balance between extinction of some taxa and the evolution of others. What causes concern is that current rates of extinction are many times the natural background rate.

The present accelerating loss of species has been likened to mass extinctions of the geological past, where five particularly prominent "megaspasms" of extinction have been identified from the fossil record (Jablonski, 1986). Present extinction rates are at least several hundred times the current natural background rate, and it is argued that they will rise several orders of magnitude by early next century to constitute the greatest mass extinction for at least 65 million years (Myers, 1979; Ehrlich & Ehrlich, 1981; Jablonski, 1986). A unique feature of the present mass extinction is that it is primarily due to the impact of a single species, *Homo sapiens*.

Extinction rates are surprisingly hard to measure, especially on a global scale. What can now be measured reasonably accurately is the rate of loss of habitat. Remote sensing backed by ground surveys provides the key to this. The Global Environment Monitoring System (GEMS) and especially the Global Resources Information data base permit measurement on a continuing basis of habitat loss.

The emerging picture is disturbing. Taking evergreen, moist tropical forests as an example, there were probably about 1.6 billion hectares worldwide before widescale human-caused deforestation began to accelerate. Current deforestation rates have been conservatively estimated at about 30 hectares each minute or 15 million hectares annually; other estimates range up to over 26 million hectares each year (Roche & Dourojeanni, 1984; Myers, 1984a; Gradwohl & Greenberg, 1988). Of this, about 4.5 million hectares are disrupted by commercial logging, 2.5 million hectares by nonsustainable gathering of fuelwood, and at least 2 million hectares as a result of cattle ranching. But one of the principal forms of deforestation is the wave of slash and burn agriculture following opening up of forests by roads. Loss of forest due to small-scale cultivation involves perhaps as many as 250–300 million people occupying about 22% of present-day moist tropical forests (Myers, 1986a; Gradwohl & Greenberg, 1988). There has already been a loss of 27–37% of these forests, and a further 12–25% is likely to be lost before the end of this century (Simberloff, 1986).

However, not just loss of area is important, but also loss of quality. What to the layperson is intact forest may be botanically depauperate. Moist tropical forests, along with Mediterranean-type ecosystems, are noted for their high level of biodiversity and for complex networks of interacting animals and plants.

Modern technology permits habitat conversion and timber extraction at rates undreamed of in the past. The tropical lumber industry has been likened to mining with extraction rates in most cases well in excess of sustainable yields (Whitmore, 1980).

For some smaller areas, such as the Brazilian state of Rondônia, quite precise data are available (Myers, 1986a; Prance, 1986, 1987). Rondônia has an area of 243,000 square kilometers, and before 1975, 1,200 square kilometers had been cleared of forest. At that stage, the population averaged about two people per square kilometer. By the late 1970s the population was increasing by almost 16% each year. Between the end of the 1970s and 1985 it doubled to over one million, an increase of over 1,000% since 1968. As the population increased so did deforestation, with more than 10,000 square kilometers cleared by 1980 and 17,000 square kilometers by 1985. Today there is a vast network of roads and farms throughout the forest, and removal of forest continues. The tragedy is that the rich soils that attracted farmers to Rondônia also made it home to a rich assemblage of indigenous animals and plants, many endemic to the region.

As the forests disappear, so do their component species. Worldwide, an alarming number of species are down to only a few individuals. An extreme example is the St. Helena olive (*Nesiota elliptica*), which is a monotypic genus and is only known from a single plant. Despite moderately successful initiatives to save the St. Helena flora, the St. Helena olive is still critically endangered (Cronk, 1987). Seed rarely sets and cuttings seem nearly impossible to strike. The remaining tree is old and vulnerable.

Similar examples come from the Pacific lowland of Ecuador, regarded by Myers (1988b) as one of the three most critical tropical forest "hot spots" where biodiversity is under threat. Since 1960 the original rainforest has been almost totally eliminated and converted to cash crops. A small remnant at Río Palenque of less than one square kilometer is now the only remaining site for 43 plant species, of which a good number, including *Dicliptera dodsonii* (an attractive vine known only from one plant) and the useful timber tree *Persea theobromifolia*, are known from very few individuals (Gentry, 1977; Lucas & Synge, 1978; Myers, 1988b). The adjacent Centinella Ridge once supported 100 endemic plant species which were eliminated by clearance for agriculture between 1980 and 1984 (Gentry, 1986; Myers, 1988b).

Loss of species, especially those with human appeal, sometimes attracts publicity, but loss of genetic variability within species is harder for the layperson to appreciate. Yet, in terms of usefulness to mankind and potential for evolution, loss of variability within some species may be just as significant as loss of some taxa. Loss of variability in wild populations of the Himalayan *Dioscorea deltoidea*, an important source of cortico-steroids, has direct commercial implications. Analyses of past collections indicated up to 6% of the steroid diosgenin, but recent analyses following intensive harvesting of wild populations have failed to reveal plants with more than 1% of this chemical (Gupta & Sethi, 1983).

Genetic erosion, which is "the loss of genes from a gene pool due to the elimination of populations because of such factors as the adoption of modern varieties and land clearing" (Plucknett et al., 1987), is an increasing problem. As farmers have adopted modern crop varieties and agricultural practices, they have tended to shift to monoculture and genetic simplification of farmlands. The genetic base of crops entering world trade has narrowed because of this. Simultaneously, there has been genetic erosion of wild genetic resources and landscapes through reduction in habitat quality and quantity, and extirpation of many populations containing distinct genotypes.

The significance of genetic erosion is demonstrated by the battle against grassy stunt virus in rice. This proved a serious pest of rice throughout much of South and Southeast Asia between the 1960s and late 1970s. The International Rice Research Institute (IRRI) tested thousands of breeding lines and wild species samples for resistance. Only a single sample, collected from a population of Indian *Oryza nivara* in 1963, showed resistance, and even this was restricted to three plants out of the sample of 30. From these three plants came the virus-resistant gene which was bred into cultivar IR36 and is now found in every high-yielding cultivar of rice grown in tropical Asia (Hoyt, 1988; Plucknett et al., 1987).

Losses are not confined to tropical forests. Alarming depletion rates are encountered in many ecosystems around the world. One-third of the planet's land area is semiarid or arid. In the arid tropics, desertification is a major problem, chiefly through unsustainable levels of agriculture, excessive removal of woody plants for fuel, faulty irrigation, and poor range management. Each year about 12 million hectares of this land deteriorates to agricultural worthlessness (Myers, 1984b). Mediterranean-type vegetation of some arid and semiarid regions is often highly diverse, sometimes with many extremely local endemic species. However, as despised so-called nonproductive "scrub," it is frequently at risk through clearance for farmland and housing. The highly distinctive Mediterranean-type shrublands of the South African Cape are among the most diverse plant communities known, yet over 1,300 of their component species are under threat (Hall & Veldhuis, 1985), and perhaps as many as 350 plant extinctions may occur in the next 30–50 years unless major action is taken to rescue species (A. V. Hall, pers. comm. 1988).

Wetlands are particularly at risk, and increasing numbers of wetland species are found in lists of threatened species. Particularly alarming is pollution by new ultratoxic compounds formed through the dumping and subsequent mixing of substances such as chlorine and thiocyanates (Kaul, 1983). A complication in the management of wetlands is that they are often subject to natural periodic fluctuations in water level. These can be extremely difficult to replicate, especially when wildfowl shooters, fishermen, boat-owners, and other users demand different water levels to suit their particular requirements (Keddy & Reznicek, 1986; Spence, 1982). Edward Maltby (1986) pointed out that with the extirpation of wetland species we lose many opportunities to study such processes as anaerobic metabolism, salt tolerance, and natural detoxification.

Even in apparently pristine regions there is loss of habitat along with local extirpation of plants. The Antarctic is often cited as the last untouched wilderness, but even here, where less than 1% of the continent is ice-free, plants compete with Antarctic bases and camps for suitable habitat along the coast (Given, 1987). This raises many questions regarding the adequacy of environmental assessment and protection procedures in such regions, as well as the need for more stringently managed protected areas.

It is not enough to shut people out of a protected area. David Ehrenfeld (1986a) pointed out that you may be able to keep people out but you cannot fence out their introduced plants, acid rain, ozone, insecticide residues, drifting herbicide, heavy metals, and atmospheric particulates. He gave the example of Huchison Forest at Rutgers University, where entry is limited and the site is used only for "unobtrusive" ecological research. Yet the forest is increasingly invaded by alien animals and plants.

Present Efforts and Future Focal Points

An impressive effort is being made at present to conserve plant diversity worldwide. In the 1960s this started to gain momentum, leading to inventories, Red Data Books, population monitoring for conservation purposes, and setting aside reserves primarily for conservation of plant taxa and gene pools.

The most widespread and perhaps the most cost-effective means of conserving plants is by preservation of natural habitats. Many thousands of protected areas play a valuable role in preserving plants. They range from large national parks to small intensively managed nature reserves and remnant strips along roads and railways.

Some reserves require precise and constant management. In the fens of Cambridgeshire in England maintenance of specific water levels is critical to the survival of vegetation and rare species. In an increasing number of instances, depleted populations of plants are being reinforced by replanting programs, or there is deliberate habitat rehabilitation. However, this is usually costly and time consuming; too often management is minimal and best described as benign neglect. Too many protected areas exist only on paper. They have not been surveyed, gazetted, fenced, or properly identified on the ground, or their management is such that the features for which they were set up are no longer protected.

A second major approach to conservation is through botanic gardens or arboreta. There are probably about 1,500 botanic gardens worldwide, but their geographic distribution is far from satisfactory. About half are in temperate Europe. Of the remainder, only 30 are in tropical Africa, about 60 in South America, and just over 120 in tropical Asia—all areas of high biodiversity. Many gardens maintain large, botanically valuable collections and some have a long history of involvement in conservation. Some of the earlier tropical gardens were established as acclimatization gardens. The botanic garden at Bogor in Indonesia is the repository for large collections of species from Southeast Asia, including many of economic importance. Some gardens concentrate exclusively on indigenous species; examples are the National Botanic Gardens in Canberra, Australia and Kirstenbosch near Cape Town, South Africa. Both of these gardens have laboratories to carry out conservation research on rare species, involving study of propagation and reproductive biology, ethnobotany, and habitat requirements.

The 1980s have seen interest generated in setting up botanic garden networks; for instance, the Center for Plant Conservation with a network spanning North America. The National Collections Centre based at Wisley in England has identified several hundred collections of national significance in the United Kingdom. Following initiatives at the Las Palmas botanic gardens conference in 1985, 1987 saw the launching of the Botanic Gardens Conservation Secretariat, which now incorporates over 140 gardens in 26 countries.

Systematic storage of seed and other propagating material in gene banks plays a vital role in conservation of crops and their wild relatives (Plucknett et al., 1987). Thirteen agricultural research centers are coordinated through the Consultative Group on International Agricultural Research, including the network coordinated by the International Board for Plant Genetic Resources (IBPGR) and centers such as the Rice Research Institute. There are many problems associated with long-term storage of wild species. Some species have very short-lived seeds, while in others seeds are recalcitrant or require specific germination procedures, which are difficult to simulate. Small numbers of available propagules can cause problems for gene banks used to dealing in hundreds of seeds or tubers in each sample. Some conservationists have concluded that seedbanks are expensive and vulnerable, and inadequate to preserve more than a fraction of even the recorded varieties of crop plants (Ehrenfeld, 1986a). Nevertheless, despite some shortcomings, gene bank storage should be attempted as an integral part of any long-term endangered species program. By the year 2000 over 90% of remaining variations of major crops should have been collected, stored, and evaluated, and many close wild relatives of crops will have been collected. By then the role of cryopreservation will have been assessed, and collecting and handling techniques for vegetative germ plasm will have been markedly improved (Plucknett et al., 1987).

Conservation is moving away rapidly from total reliance on traditional techniques to utilize new technology. In western Australia satellite data were used to locate habitat of the rarely seen subterranean orchid *Rhizanthella gardneri*—the data showed the orchid to be associated with a specific host and more widespread than formerly thought (Dixon & Pate, 1984). Electrophoresis and, less often, DNA analysis are being used to assess population variation and to elucidate probable breeding systems. Isozyme analysis of Californian conifers and Australian narrow-range endemics, e.g., *Eucalyptus caesia*, is indicating considerable genetic differences between species that otherwise appear similar and assists in estimating minimum viable population sizes. Tissue culture is being used for some orchids and other plants that are difficult to propagate by conventional means. Callus tissue can also serve to propagate plants in large numbers at predetermined times of the year for reestablishment in the wild.

Legislation and education are vital aspects of threatened species programs. In the international arena, the Convention on International Trade in Endangered Species of Fauna and Flora (CITES) plays a major regulatory role. Many countries have enacted legislation to protect rare and endangered species and their habitats, although often this is applicable only to the plants found on state-owned lands or to taking of plants for commercial purposes. Legislation and regulation are starting to give greater acknowledgment to traditional uses of and attitudes toward plants; this also involves recognition of traditional forms of resource ownership such as common property regimes.

A vital role of botanic gardens in particular must be to create an awareness of the need for plants and their conservation. The proportion of urban people in most countries is steadily rising; in 1980 half the world was urbanized, but by the year 2000 75% of people will live in cities. For these people botanic gardens provide a window into nature. For protected areas, too, education and awareness are important components of management. Study of a rural community's attitudes to a nearby conservation area in Natal showed that positive attitudes were generally correlated with greater affluence and education, and particularly with direct experience of the benefits of the conservation area (Infield, 1988). This suggests that it is important to involve local people in conservation programs. A remarkable example of this is found at Guanacaste, Costa Rica, where Dan Janzen is involving local people in management, "hands-on" education, and interpretation. Janzen's philosophy is that the remnant forests of Guanacaste are a library, an archive, and a classroom for the indigenous people, as well as serving valuable scientific and conservation functions (Janzen, 1986).

The 1980s have seen increasing stress on demonstrating the value of biodiversity and the usefulness of plants to people. To some extent this has been a process of rediscovery by the developed nations of what was well known to many traditional societies in less-developed parts of the world. Ethnobotany has acquired a new respectability by demonstrating the degree to which wild plants are used (e.g., Myers, 1984a; Hanks, 1984; Plotkin, 1986; Prance et al., 1987). Quantitative studies of the use of trees by four tribes in Amazonia show that these rainforests contain an exceptionally large number of useful trees; up to 76% of tree species on inventory sites can be "useful" (Prance et al., 1987). About 75% of the medical needs of the

Third World are met by traditional herbal remedies (Adesiwojo et al., 1984). Scores of locally cultivated crop plants have potential to supplement the 20 plants that contribute 90% of the world's food. These include more than 20 root crops, legumes, grains, and fruits found in South America, which are "lost crops of the Incas" (Vietmeyer, 1986). There are conflicts: should ethnobotany stress "discovery" and commercialization of plants for worldwide use, or should it encourage a retention of traditional use; and should the emphasis be on conservation of plants and their habitats because they are "useful" to mankind?

Documentation, inventory, and monitoring are vital to all conservation strategies. It is essential to know not only what taxa are at risk, but the trends and priorities, and whether strategies are successful. At the global level key roles are played by organizations such as IUCN's monitoring center at Kew, the specialist groups of the IUCN Species Survival Commission, The Nature Conservancy, Conservation International, and WWF. Their role is crucial. But they cannot do all the work. There is urgent need to enhance existing national and regional data bases and to establish new ones.

Inventories are showing that in many countries 10–15% of the vascular flora is likely to be at risk. Unfortunately, only sketchy data are usually available for cryptogams, and there is urgent need to assess the risk for these. There is also an urgent need to develop a monitoring system at the population level that is useful to the local manager of a protected area and can contribute to global estimates of depletion. The Plantwatch concept—as it has been christened by IUCN—must be simple and quick to operate while asking the relevant questions. An important project is the identification and assessment of centers of plant diversity, some of which are global "hot spots" under a high degree of threat (Myers, 1986b, 1988b). In just three of the "hot spots" for tropical forests (Madagascar, the Atlantic coast of Brazil, and western Ecuador), Myers (1988b) estimated that some 6,200 plant and 124,000 animal species could become extinct. A pilot scheme developed by IUCN at Kew has identified almost 160 centers of plant diversity around the world. Greatest numbers are in tropical South America, Asia, and Africa, including oceanic islands such as Rapa, Mauritius, St. Helena, and the Chatham Islands (IUCN, 1987). These are key sites to monitor the state of biodiversity and must be priorities for recovery projects.

Despite past and present achievements, there must be some doubt as to whether they will stem the tide of biodiversity loss. As we move toward the twenty-first century, several focal points emerge. These are the need for a more biological approach with greater understanding of persistence and extinction processes, development of management strategies appropriate to human-disturbed ecosystems, adequate resources for conservation, greater innovation and boldness, and development of a renewed conservation ethic.

Understanding Persistence and Extinction

Prevention of extinction and maximizing persistence are major complementary aims of conservation. Yet we are far from a full understanding of either persistence or the precise mechanisms of extinction and their relationship to such factors as viable population size. A major change of perspective has been the adoption of a systems approach in the early 1980s distinguishing deterministic extinction from chance or stochastic extinction. It shows that four separate forces make key contributions to population extinction (Schaeffer, 1981). These are: demographic stochasticity (variation in population size leading to unacceptably low numbers), genetic stochasticity (excessive inbreeding and loss of selective variation), environmental stochasticity (environmental shocks received by all members of a population), and catastrophes.

This work has been extended by Gilpin & Soulé and incorporated into a conceptual model that recognizes three components (Gilpin & Soulé, 1986): "population phenotype," "environment," and "population structure and fitness." Environmental changes set up feedback loops of biological and environmental interactions that impact the population negatively. Gilpin & Soulé referred to these event trains as "extinction vortices" that can lead to extinction. They identified four distinct vortices triggered by various combinations of chance decrease in population size, decrease in genetic effective population size, decrease in population growth rate, and increase in the variance of population growth rate. The vortices can operate over different time scales and can interact in different combinations.

An important advance has been to distinguish deterministic extinction (when something essential is removed, such as habitat or food, or when something lethal is introduced, such as predation) from stochastic extinction resulting from random changes or environmental perturbation.

The Gilpin & Soulé model has several practical implications. It identifies demographic stochasticity as often being the immediate precursor to extinction, justifying concern for the future of small populations. It also indicates that two important factors in long-term persistence are the maintenance of relatively large areas of habitat and sufficiently large populations to ensure that random effects do not result in loss.

Genetic aspects of extinction and especially the effects of loss in heterozygosity are often emphasized. Concentration on loss in genetic variability alone may overlook other stochastic factors or the possibility of loss through catastrophe. Especially in highly dynamic ecosystems, such extirpation may result from other effects long before loss of fitness is significant.

Well-documented case studies of extinction in regions of high risk are urgently needed. One ongoing project that should provide some insights is the Minimum Critical Size of Ecosystems Project in Amazonia sponsored by WWF(US) and Brazil's National Institute for Amazon Research (Lovejoy et al., 1986). This is a long-term attempt to determine the effects of fragmentation on habitat and species. It takes advantage of the decree that when land is cleared for farming, 50% must be left as standing jungle. At the project site the pattern of clearance is designed to leave remnants of varying size from one hectare up to 10,000 hectares.

Results of the effects of size and area are starting to emerge; for instance, the decline of some animal populations in remnants up to 10 ha (Lovejoy et al., 1986). As one species is lost, populations of other species may also decline. The smallest Amazonian reserves are not large enough to support populations of army ants. As they disappear, so do birds dependent on the ants for food. The loss of these birds is likely to lead to loss of interacting species that are dispersal agents or pollinators for plants. Loss of the ants also affects decomposition of plant matter and the recycling of nutrients.

It is not sufficient to assume that once a population has reached a predetermined "safe" size it will survive for the forseeable future. Persistence is concerned with the probability that under certain conditions and with a population of particular size, there is X probability of existence for Y number of years. But the selection of persistence times has an ethical aspect. Some people might be content with a low probability of persistence for 100 years whereas others might demand a very high probability for 1,000 years.

An important aspect of extinction theory is that processes for plants may not be quite the same as those for at least some animals. Examination of palaeobotanical data and comparison with data on animal fossils shows that, although there are comparable bimodal extinction rates, major changes in the composition of vascular plant floras have not coincided with similar events in the animal kingdom (Knoll, 1986). Knoll suggested that in many instances plant extinctions appear to be related to competition with newly evolved taxa or to climatic change rather than other extrinsic events that have been suggested as causative factors in some animal extinctions.

Above all, a more rigorous biological approach to conservation is needed. Even such elementary data as broad classes of breeding system, pollination and dispersal vectors, and germination requirements are generally unknown for threatened plants. This seriously hinders development of effective management programs for plant species. There is a severe shortage of experienced ecologists who can make management decisions for large areas of rainforest, wetlands, and shrublands. There seem to be no lack of students who want to be ecologists (or taxonomists and reproductive biologists), but as Les Kaufman vividly expressed the problem (Kaufman, 1986): "Ecologists somehow never quite 'made it' alongside those professionals whose services are viewed as essential to society. . . . But what about a messed-up ecosystem? We have yet to produce a school of competent ecological engineers."

Managing in Modified Habitats

If one thing can be guaranteed into the early part of next century it is expansion of man-modified landscapes. This will be a natural consequence of increases in numbers of humans and the consequent need for land to provide more living space, food, and fuel.

Our species has just reached 5,000 million individuals and by the year 2000 should stand at about 6,000 million. A peak of perhaps as many as 15,000 million early in the twenty-second century has been frequently forecast, although the Global 2000 study suggested a peak as high as 30 billion (Barney, 1980). Technology may allow production of more food and fuel on less land and may reduce pollution levels in the future, thus slowing the rate of habitat loss. Methods for habitat rehabilitation are being developed. But there will be an unavoidable time lag in application of such technology. A significant factor will be the availability and cost of appropriate technology. Largest population increases are in the many countries that total only an 18% share in world expenditure on research and development (Myers, 1984b). Economics may dictate hard choices regarding the amount of pristine habitat and wilderness that each country can afford.

In regions that are highly modified through human influence, five particular factors can profoundly affect wild populations.

1) First, the landscape becomes "frozen in place" as attempts are made to control such natural processes as floods, fires, predation, and erosion so that their effects become minimal in a static pattern of towns, roads, farms, orchards, and remnant nature reserves. This can have serious consequences for many species. They can no longer move from one site to another in a continual pattern of local extinction and recolonization. Species become attuned to patterns and magnitudes of natural disturbance and stress, which are likely to be drastically altered in highly modified ecosystems.

Orothamnus zeyheri—a monotypic genus of the Proteaceae from South Africa—is just one example. For many years botanists had condemned the destructive effects of fire on the Cape Flora, resulting in fire protection. Investigation showed that this policy resulted in the decline of many species, including *Orothamnus*, which was reduced to 34 plants in four sites by 1968. Research showed that the species has natural cyclical fluctuations dependent on intervals between fires, with an optimum periodicity of 15 years for firing (Boucher, 1981).

One of the consequences of fragmentation of the landscape into a static pattern of land use is that conservation must become an integral part of land planning. There is also need for adequate mitigation processes and flexible options for preservation. Conservation of islandlike patches of habitat with narrow-range endemics in the San Bernardino Mountains of California, U.S.A., (Krantz, 1987), involved negotiation with five governmental agencies over ten years as well as detailed biological assessment and identification of key sites. A key device in this exercise is a regional biotic resources map, which assists selection of the best and most manageable sites for protection.

2) The second factor is isolation of patches of suitable habitat. Connecting corridors that facilitate gene flow, seasonal movement, and migration are lost.

3) The third factor is reduction in size of suitable areas of habitat. This has two main consequences. Some sites become so small that they are dominated by edge effects, and no undisturbed core habitat remains. Species in need of such core habitat die out and their place is taken by opportunist plants. The second consequence is reduction in population size so that random stochastic forces place the population at risk.

4) The fourth factor is increased competition with weeds. In a consultant's report to the last IUCN/WWF Plant Advisory Group meeting, although Cronk (1988) identified invasive weeds as an extremely serious environmental problem, he pointed out that "there is an extraordinary information vacuum where invasive plants are concerned." Similar conclusions were reached 1987 by a workshop on botanical management of the Galápagos Islands. There, such plants as *Cinchona succirubra* (quinine), *Lantana*, and the common guava threaten endemic plants of these unique oceanic islands (Adsersen, 1989).

5) Related to this is the fifth factor: predation. The effects, sometimes disastrous, of exotic herbivores on island floras is well documented. Today, predation by a wide range of animals, including goats, pigs, deer, chamois, and feral sheep and cattle, is a serious problem in many parts of the world. But smaller and sometimes overlooked organisms, such as fungi and viruses, can also have significant effects on plant populations. Disease transference from cultivation crops or nursery-propagated stock to wild plants must be guarded against, especially when executing recovery programs on oceanic islands. Cucumber mosaic virus has been detected in cultivated plants of the notable Chatham Islands endemic *Myosotidium hortensia*. Transfer of the virus to wild populations could have serious consequences for the species. Similarly, transfer of *Phytophthora cinnamonii* into previously uninfected areas can be a risk without stringent hygiene.

In landscapes highly modified by human activity there is special need for a series of key indicators of population health. These could collectively suggest which extinction vortices are involved, and the immediate and long-term remedial action required to prevent extinction. Halting population decline to low levels will be a critical aspect of this.

Plantations of exotic plants for timber and wind shelter have been neglected as potential havens for other plants. Yet, sometimes they can contain a surprisingly diverse and rich flora. In South Africa substantial populations of endangered members of the Cape fynbos flora have been found in pine plantations. In New Zealand the Iwitahi Reserve has been established in a mature stand of *Pinus nigra*. Twenty-seven species of native orchids are found here, including *Chiloglottis gunnii*, which is classed as vulnerable in New Zealand (Gibbs, 1988). Such habitats must not be regarded as necessary substitutes for undisturbed sites. But their potential role in conservation, especially in highly modified, peri-urban lowland regions, has been underestimated.

In highly modified landscapes interventionist management is unavoidable, and the objectives of such intervention need to be unambiguous. For many plant communities—especially in temperate regions—high and low levels of disturbance are likely to lead eventually to low levels of species diversity, which may be the natural state. However, if biodiversity is maximized in a particular region (especially given the fragmentary nature of many habitats), communities may have to be perturbed to promote the development of "unnatural" species-richness. It may be that some "naturalness" has to be sacrificed in the short term in order to maximize biodiversity.

Adequate and Appropriate Resources

Global expenditure on science and technology is very unevenly distributed. Approximately 82% of the effort on science and technology is in the developed nations with 20% of the population. The global communications system is controlled by those same countries (Myers, 1984b). Regions with the greatest need for scientific expertise may have least access to it. A critical evaluation of floristic knowledge in Latin America and the Caribbean by Toledo (1985) pointed out that this region has perhaps the world's greatest botanical diversity. Yet it lacks the indigenous resources to inventory fully and conserve that diversity. The 27 countries involved have over 900 resident botanists, but this contrasts with the 1,500 amateur and professional botanists in Great Britain alone. Colombia has an estimated 45,000 vascular plant species but only 47 resident botanists in 1985, and in 1981 had fewer than 350,000 plant specimens in its herbaria. A counter to this is the considerable botanical investment in Latin America by agencies such as Missouri Botanical Garden, Field Museum, New York Botanical Garden, and WWF (US). Nevertheless, Toledo concluded that the urgent need to inventory the great wealth of New World plants, the accelerated rate of habitat destruction, and limited resources implies: "collecting and correctly inventorying the greatest number of species possible in the least amount of time, that is, an endeavour which Fosberg once called a 'salvage botany'."

A second problem is that we are inundated by a flood of knowledge. Words flood the world and the entry of data processing in the 1970s seems to have done little to control and systematize the flow of information. Most scientists and managers know the problem of always seeming out of date, even in the most limited subject. Despite the most rigorous library and data base searches, there are always new papers and bulletins being published, journals that one cannot access, and incidentally discovered unpublished reports. New journals and newsletters are being proliferated at a rate that taxes the ability of most libraries to keep up to date. Language provides a barrier, and there is too little contact between scientists with different primary languages.

The effects of the information flood are compounded by a third problem—the subjection of science to marketplace economics. In the most ruthless form of free-market enterprise, science becomes a tradable commodity expected to return a profit to its financiers. This can result in a scramble for funds with competition between formerly cooperating departments of state, universities, and research organizations. The "free market" philosophy in science has "somehow changed the role of scientific enquiry in our society to a materially driven pursuit which is indistinguishable from marketing, labour relations, product development or pollution control. It is a key component of an industrial society. But it is much more than that. [. . .] it is very important that our citizens—particularly our young people—appreciate the cultural and intellectual significance of scientific enquiry" (Upton, 1988).

Transformative values in science have been a driving force in scientific investigation throughout civilized history. Conservation biology is not just to determine the best way to preserve biodiversity so that we can use it better, faster, and more efficiently—it also serves to open to our minds a world that is infinitely varied and has inspired poets, writers, and thinkers through the ages.

Stringent curbs on conservation expenditure, such as are occurring in many countries, can place the scientist and manager in an invidious position. Which species are allocated money for research and preservation? Can predator and weed control be undertaken? Are botanic gardens a luxury? Should limited resources be used to buy areas of wild habitat? When the choice is jobs or species preservation, which goes first? Problems of resource allocation are unlikely to improve in the near future unless there is a drastic change in attitudes toward nonhuman species. Increasing numbers of people and greater demands on space will mean less space for wild plants and animals, and diminished resources for conservation.

Conservationists of the future may be faced with the problem of triage: having to determine which species will slide toward extinction because there are insufficient resources to save them, which are not yet in need of urgent attention, and which can be treated with existing resources. It is tempting to put large amounts of time and money into a small number of spectacularly endangered species with public appeal while allocating little to species with less appeal or that are becoming critically endangered. In terms of conservation of overall biodiversity, it might be better to spend more on preventing species from reaching critical levels of endangerment.

Communication and Cooperation

Cooperation means assessing the strengths and weaknesses of contributing people and organizations, and then making the best use of each other's strengths and countering their weaknesses. It means maximizing use of resources, especially where these are scarce. At the simplest level it may also mean using the same vehicle to get researchers from different agencies onto field sites; at more complex levels it may mean closely integrating research and management programs and sharing major resources, such as herbaria, gardens, and laboratories. The need for cooperation exists at all levels from local and regional to national and international.

The trend toward an increasing degree of specialization and a view that "only engineers are qualified to talk about engineering, only biologists can talk about biology . . . etc." can result in a dearth of people who can bring such disciplines together cooperatively. There can also be unwillingness for people to speak to others outside their own speciality or to question the assumptions and conclusions of these other specialists. Yet we all need to question and understand viewpoints from other disciplines and cultures.

National and international organizations have a major contribution to make in promoting cooperation and good communication. The setting up of the joint IUCN-WWF Plant Advisory Group is just one of several positive moves to achieve this, but it is essential that such groups be in touch with what is actually happening in the "real" world. The urgent need in conservation is hands-on botanists and managers rather than desk-top administrators and prophets. Cooperation, especially in tropical countries, means involvement of local people, "grassroots support," rather than grandiose schemes run by expatriots. It is important that indigenous people and their knowledge be involved in setting up and managing nature reserves, restoration of habitat, and maintenance of sustainable forms of agriculture. Examples in Gradwohl & Greenberg (1988) show that through communication and cooperation, wise use and preservation of biodiversity can be achieved.

For most of the last two years I have been working on a global synthesis of the principles and practice of plant conservation. The project is both challenging and frustrating. One of the greatest pleasures has been to communicate with and learn from many hundreds of people, some working in the most out of the way places. It is a humbling experience, yet frustrating because many of these people with such good ideas and relevant experiences do not get the chance to share with others as they should. In many instances they do not have the resources to attend conferences and workshops outside their region; in other instances they are too busy performing practical conservation.

Innovation and Boldness

Two things that may determine much of the effectiveness of future conservation are innovation and boldness. If the situation in the early part of next century approaches worst-case scenarios, every bit of innovation and boldness may be needed to avoid vast numbers of extinctions, especially in the tropics.

A novel extension of the botanic garden concept is the idea of setting up a "Noah's Ark" refuge for species, especially for the establishment of plantations of northern hemisphere trees threatened by acid rain. This has been suggested several times in the last five years for isolated countries, such as New Zealand, where pollution is relatively low, and land is available. There are problems: are whole communities or ecosystems to be shifted to their new island home? Who pays? Will some introductions adversely affect indigenous plants through competition or introduction of new predators? Will expenditure on such a "Noah's Ark" downgrade efforts to conserve indigenous species? An overall problem is the question of "how long" will the ark have to accommodate species from defunct habitats? It is one thing to assume that ex situ conservation on a massive scale is permanent, but quite another to regard it as a temporary expedient for several decades (or even a century) until suitable habitats can be rehabilitated or created.

Establishment of new populations of plants in quasi-natural sites where they have not formerly occurred is similar to the "Noah's Ark" concept.

It may be justified where predation makes it impossible to preserve a species in its former habitat. The transfer of animals and plants to goat- and rat-free off-shore islands is an example of this. Another situation where it may be justified is where each population is reduced to only one sexual state, and the most reasonable chance for sexual reproduction is to establish a completely new population with a mixture of plants from remaining sites. New Zealand's *Gunnera hamiltonii* provides an example, being known from only four single-sex populations.

In some extreme instances the genome of exceedingly rare species might be transferred into related and more common species, either through hybridization or genetic engineering. This brings into question the ultimate goal of conservation: whether the preservation of species or of biodiversity. If the latter, then one can argue that it matters less how valuable genes are preserved than that they be preserved somewhere and somehow.

There are various ways in which in situ and ex situ approaches can be combined to make persistence of a small population more likely. One technique might involve maintenance of some areas of suitable habitat and harvesting of seed, sampled to maximize genetic diversity. Some of this seed would be banked for long-term storage as a precautionary measure against catastrophe, while some would be used for garden propagation and replanting back into the wild site. In effect, population size is maintained above a critical level by a combination of in situ preservation in the wild and ex situ preservation in gene banks, laboratories, and botanic gardens.

If models of global warming through the "greenhouse effect" are valid, every scrap of ingenuity may be needed to conserve biodiversity in the twenty-first century. Although some aspects such as sea-level rise and fluctuations in ocean and atmospheric circulation are hotly debated, it is not too early to consider possible scenarios and their implications for conservation. Climatic shifts will have a number of serious consequences (Peters, 1988). Changes in species distribution can be expected as conditions become locally unsuitable for persistence. In some long-lived species, although adult plants may remain, this will result in a regeneration gap, especially where germination or seedling growth requires seasonal chilling. Spectacular initial losses are likely to involve arctic-alpine species at relictual sites, such as *Rhododendron lapponicum* at Wisconsin Dells or the post-glacial disjuncts along the north shore of Lake Superior (Given & Soper, 1981).

For many species the choice will be to migrate or be extirpated. But suggested rapidity of climate change means that migration rates required will exceed natural migration rates for many species. Today's fragmented landscape offers a formidable obstacle course to migrating species. Peters (1988) gave the example of *Picea engelmanii*, which would require over 1,000 years to adjust its range to a new climatic regime.

To mitigate climatic change requires several courses of action (Peters, 1988; Myers, 1984b). Refinement of "greenhouse" models is urgently needed, and selected species in regions where early effects can be detected should be monitored without delay. Preservation of representative populations throughout the whole range of species is another strategy; often there has been a tendency to be satisfied with one reserve for a species. In all reserves there need to be contingency plans for modification of drainage and irrigation to allow for changes in moisture regimes. Changes in weed and predator distribution are likely and could profoundly affect some species. This requires early identification of such problems. It makes sense to locate new reserves at the poleward end of species ranges (because of poleward retreat of temperature-sensitive species). Particular reserves should maximize diversity in habitats and altitudinal gradients.

At least in the short term, an important role must be assumed by botanic gardens and gene banks to ensure that plant diversity that may have difficulty surviving in the wild is preserved. This challenge needs to be taken up at all levels, from the local garden and research center to international organizations such as IUCN and IBPGR.

The limitations of ex situ conservation have been pointed out by Foose (1986) with respect to animals. He argued that the capacity of the "zoo ark" to cope with at least 1,500 mammals, birds, reptiles, and amphibians expected to be endangered by the middle of next century is very limited. As a consequence, the American Associaton of Zoological Parks and Aquariums has designated through its Species Survival Plan 37 priority taxa for ex situ preservation. The eventual aim is to have up to 1,000 species designated. However, this will still fall far short of requirements for the next century.

Similarly, it is debatable whether botanical gardens and gene banks can eventually guarantee the persistence under ex situ conditions of their share of the world's biota, at least without a great deal of reorganization. If the number of botanic gardens could be doubled and each persuaded to take prime responsibility for ten different plant taxa under threat, we would be a long way toward shepherding the flora of the world through the problems of next century. There have been numerous criticisms of botanic gardens and gene banks in recent years and whether their long-term role for conservation is outweighed by their deficiencies. Most of the problems cited, such as poor documentation and lack of adequate regenerative procedures for seeds, are not a reflection of fundamental problems so much as the result of poor management, unclear objectives, and inadequate finance. These are all capable of correction, provided there is a change in the fundamental attitudes of society to biological conservation.

REDISCOVERING AN ETHIC

It is easy to make facile appeals to new technology to solve environmental problems, and there is no doubting the contribution of such advances as satellite imagery to conservation today. But no amount of technology or innovation will sustain plant diversity into the future unless there are fundamental changes in attitudes to biodiversity. This means moving away from exploitation and toward sustainable systems, changes in economic systems dominated by benefit-cost analysis (BCA), acknowledging the place of nonutilitarian values such as intrinsic and transformative values (Norton, 1988), greater social justice, and equity in resource distribution. Progressively more intensive applications of science and technology to Western society, requiring increased levels of energy consumption as well as larger and more centralized structures and institutions, have increased stress in environmental and social systems in ways not reflected in conventional analyses (Dahlberg, 1987). Although lip service is paid to conservation, "In the pursuit of economic gain, most people do not want to be bothered by questions of biodiversity" (Cobb, 1988).

Is biodiversity misunderstood even by members of the scientific community who ought to be its champions? David Ehrenfeld (1986b) suggested that ecologists have been "co-opted by economists" because it is difficult for the former not to respond to arguments based on fundamental scientific misconceptions and, more important, because of the compelling power in Western society of arguments based upon numbers and resources. He contended that "most of us, apart from a few hard-core philosophers, suffer from a deep-seated fear of economists" and challenged scientists themselves to "recapture the love of diversity for its own sake."

We live in a global commons where there needs to be mutual interdependence and not independence. We need a new understanding of natural sources and resources based on a hierarchy where "genetic and biological diversity are more fundamental than renewable resources, which in turn are more basic than nonrenewable resources" (Dahlberg, 1987). It is too tempting for individuals and institutions, especially those of the developed Western countries, to be "free riders" in the global system, ignoring limits to growth and assuming that just around the corner yet another bit of technology will solve the present crises. The irony is that some of the indigenous people who may be displaced from their traditional lands by the "free riders" are the very people who have learned to live in harmony with their environment, utilizing yet conserving the plants around them. No culture can afford to be so arrogant that it ignores the cultural and technological systems of others.

Do doomsday messages cut any ice? A few days ago a letter appeared in the Christchurch *Press* following the suggestion by geologists that there was a high risk of a severe earthquake:

> Sir [. . .] This is the second, in as many days, of this kind of depressing report. It is bad enough to be bombarded daily with the horrible realities of present unemployment, inflation, crime, etc., but to have to hear of the future in such a negative way is just too much. The morale of our country, with its present problems, is low and this sort of unnecessary sensationalism in our daily papers does not help it. Why not give us articles about the positive things "likely" to happen. . . .

This has been described as the Cassandra problem, an allusion to the Greek prophetess Cassandra whose prophecies were true but not believed by their hearers. Les Kaufman (1986) pointed out that: "To some people, these Cassandras, as they call themselves, are professional doomsayers, intellectual terrorists who should not be encouraged, supported, or believed. What seems to have escaped such doubters, however, is that the whole point of being a doomsayer is to agitate the world into proving you wrong or into doing something about it if you are right."

There is no lack of publications arguing the case for a change of attitude to natural resources and a new stewardship of biological diversity. A research agenda suggested by Myers (1986b) outlines nine topics as priorities for research, including extinction links, vulnerability of systems and taxa, rates of recovery from depletion, and the economics of threatened species. A study of ecological aspects of development in the humid tropics (National Research Council-US 1982) sets out a similar agenda for use of tropical resources. That governments and institutions seem to have difficulty implementing many such agendas seems to suggest that we do have a Cassandra problem, and that the difficulty is not so much one of ignorance but lack of will and commitment.

It is tempting to yield to "doom and gloom" scenarios and to give up. On the other hand, the gathering of nearly 800 participants in November 1986 to discuss conservation and management of rare and endangered plants in California, U.S.A., shows that interest in plant conservation can and should be generated (Elias, 1987). Myers (1988a) has pointed out that, despite the gloomy prognosis for many of the world's species, given the will, the means are available to stem the tide of extinction. He calculated the cost of an Action Plan to promote intensified stable agriculture, halt spread of deserts and depletion of rainforests, supply family planning services throughout the Third World, and provide clean water to 1.5 billion people as $67 billion (U.S.) a year. This is less than twice as much as current development aid. Norman Myers asks not "Can we afford to do it?" but "How can we afford not to do it?"

It seems reasonable to express optimism that the worst scenarios are unlikely to occur and we can hope for sanity and "common sense" to prevail. Is it too much to hope that by the year 2100, McNeely's (1986) scenario of a world no longer needing national parks will be a reality? As he pointed out, national parks and other protected areas are an admission that people have not learned to live with nature or are forced to live with nature.

A change to a conservation-oriented world means a commitment to social justice and equity on a global scale. It means (Raven, 1986): "an awareness of and compassion for all life, and an appreciation of the fact that we are all part of a living world. [. . .] we should not allow ourselves to respond only when the crises that we have caused are so extensive that they threaten our lives. To do so is to be thoroughly immoral in the fullest meaning of the word." To change means opening people's eyes to the positive aspects of nature; yet it also means being honest and realistic about the risks to biodiversity. The greatest danger may not be that biodiversity will be lost in a sudden cataclysm precipitated by *Homo sapiens* but that we will allow planet Earth to die by attrition. In James A. Michener's novel *Caravans*, the question is asked of a ruined desert city: "Why did it die?" (Michener, 1964). We are told: "[. . .] this used to be the world's foremost example of irrigation. [. . .] But people got lazy. They didn't keep working on it. They felt that what had worked for a hundred years was good enough for the next hundred years. They stopped building the ditches [. . .] built no new dams. They guessed right. For a hundred years, no trouble. But the death warrant had been signed." We need to ensure that the death warrant is not signed for Earth—even by default.

Conservation has a message for the world about plant diversity. But for the world to take notice may depend on heeding the advice of General Booth, founder of the Salvation Army, who pointed out that if you present good news to a starving man then you must wrap it in a sandwich. The tragedy we face through the loss of plant diversity may mean that very soon we may have tens of millions of starving people but very few sandwiches.

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